Design Decision Support through Translation between Multiple Representations of Spatial Data

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ABSTRACT

Urban planning and urban design involve collaboration of diverse participants with multiple agendas and multiple criteria. The participants typically use multiple representations of spatial data to derive inferences and insights about the planning problems, leading to a shared decision-making process. To support such multidisciplinary work, this paper proposes a new computational approach and technique for translation between multiple representations of spatial data. This approach is designed to support design decision-making in the interrelated interests of design participants. Prototype implementation and evaluation are conducted to test and validate the proposals.

1 INTRODUCTION

Architecture and urban design involve an exploration of trade off between multiple agenda, multiple criteria and at its core, a negotiation mechanism among its multiple participants (Gross et al., 1997). Planning and urban design involves collaboration between multiple disciplines and interests such as urban planners, urban designers, geographers, sociologists, economists as well as public. Each party comes with a different agenda, design criteria, and respectively its preferred representation of pertinent urban data. Polarization of views becomes a fundamental characteristic of such collaborative work and hence necessitates the use of multiple representations to resolve design decisions from different perspectives.

Graphic representations are ubiquitous in planning and urban design (Dave, 1993; Faludi, 1996). However, the complexity in representing planning and urban design arises from conflicting agendas in every design decision. In most cases, these complex and interrelated agenda cannot be presented by any single means of representation. A representation may satisfy one agenda while not satisfying the others. As a result, representations cannot be separated from associated agenda, and discipline/ individual preferences (Scaife and Rogers, 1996).

As an example, consider a representation of traffic circulation. Would it be easier to understand traffic circulation through a diagrammatic map or a walkthrough animation? Such question cannot be answered meaningfully without knowing the audience (people) and purposes (task) of presentation. For traveling purpose, train passengers may vote for a diagrammatic map that highlights the designated route and the sequence of interchanges as their preferred representation. Whereas in other situations, a diagrammatic map represented by different number and color of traffic loads may not convey much information about this variability without its associated time-based visualizations. The same question arises when designer takes into account the needs of different audiences. Designers may choose time-based animation in visualizing pedestrian experience to a novice audience. While designers may find tabulated data and charts to be more effective in convincing the developers that a street's minimum corridor has resulted in the maximum sellable land.

Despite growing recognition of the importance of multiple representations in supporting collaborative design and planning practices, there is less evidence of successful implementation. At present, most of the computational planning and design supports in the form of database and drafting applications that are used in isolation from other related disciplines. While some applications support design collaboration, there still exists limitations in current planning and design support systems (Dave and Bishop, 2000). Many applications allow data to be viewed in multiple representations such as map, table, chart and 3D model. However interaction takes place in one representation only. GIS and some specialized computer aided design applications allow translation between spatial (i.e. graphic) representation and non-spatial databases. However in these applications, relations among data traverse in one direction only, e.g. from spreadsheet to graphic representation. To extend bi-directional traversal among different representations, there is a need to systematically identify the usability and potentiality in each translation and consequent loss, if any, of information.

In this paper, we investigate the need for multiple representations in design decision-making. Using planning and urban design scenarios, we look at problems and potentials in enhancing collaborative aspects of the work. The paper is organized as follows. The first section describes a typical urban design and planning project scenario. It illustrates the necessity of using multiple representations to increase awareness of design consequences between and within the disciplines involved in process and thus articulates motivations of this project. Based on this scenario, the second section outlines the taxonomy of graphic representations and its significant translation issues. Third, we illustrate our prototype system (REX), its implementation details and preliminary evaluation of the software. Lastly, the discussion addresses various issues in using REX to support design decision-making in collaborative planning and design. It also identifies the limits in computing the translation between these multiple representations.

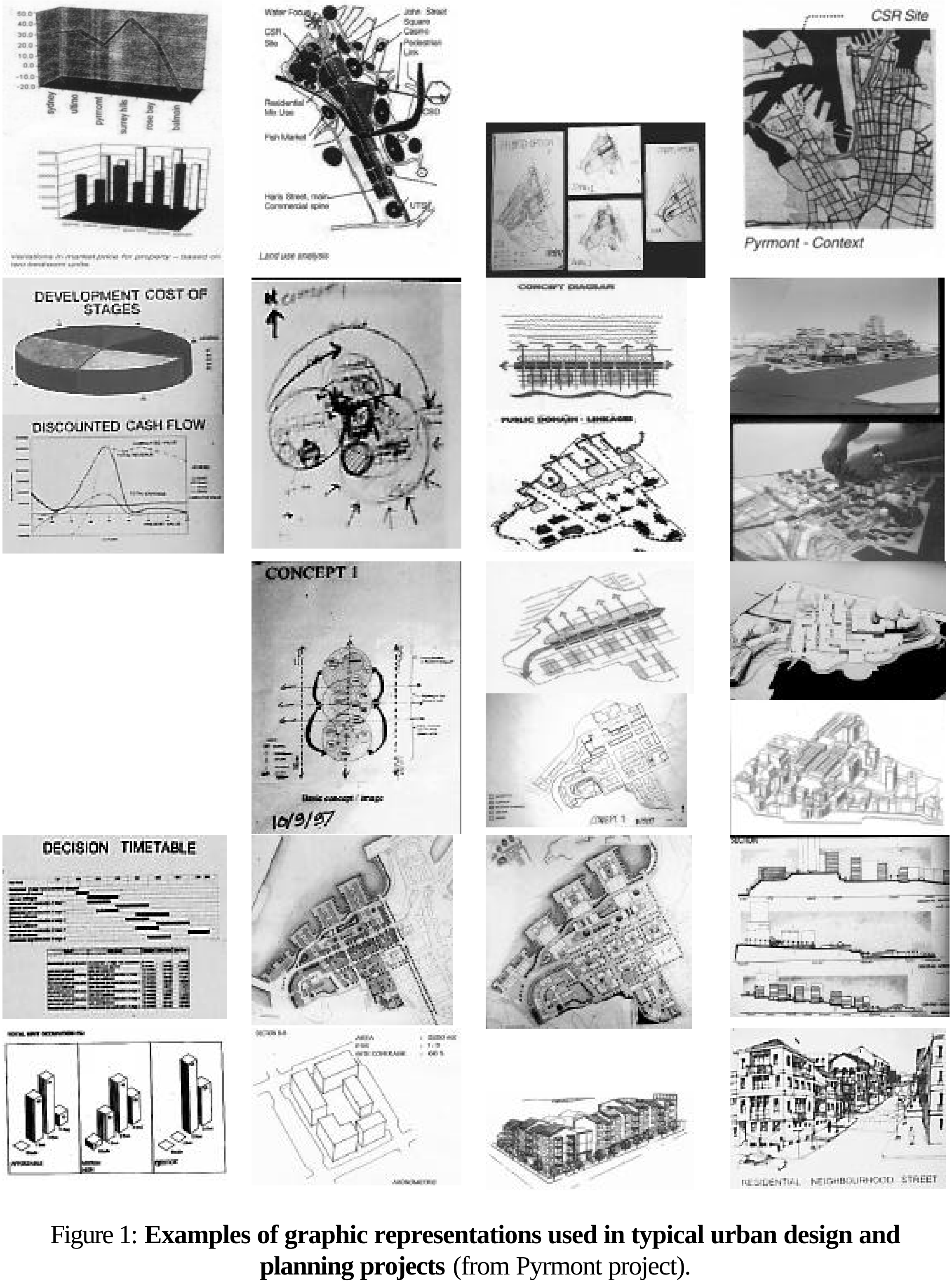

Figure 1: **Examples of graphic representations used in typical urban design and planning projects** (from Pyrmont project).

Note : Images in Figure 1 and Figure 3 are the work of Master of Urban Development and Design 97 students at the University of New South Wales. One of 3D model images in Figure 1 is taken from Lend Lease Pyrmont Site Master Plan, October 1998.

There are few empirical studies of urban design and planning projects that document in detail how a particular agenda prevails over another and the use of graphic representations in that process. Some of the reasons for this lack include the following. Design process is iterative, many negotiations (if they occur) are undertaken verbally or without formal graphic representations, and in-process representations are usually discarded at the end of the project to be replaced with final documentation. Thus much valuable data about how design and planning process unfolds are typically lost.

To investigate the relationship between graphic representations and their uses in development of design projects, the following presents a typical project development scenario. The project is based on a design studio in urban development and design in which teams of students worked together. The project brief called for development of a mixed-use community plan on a twelve hectares old sugar refinery site at Pyrmont, Sydney. The project comprised three related tasks: survey and analysis, development of the master plan, and feasibility study.

During the first stage of survey and analysis, students worked in groups of two or three, investigating different aspects of site analysis. The issues included natural landscape setting, history and planning control, economic and market, social demographic, traffic and access, and political decision-making. In response to the diversity of design issues, the use of multiple representations becomes a necessity during this stage. For example, thematic maps were dominantly used for landscape and traffic analysis whereas economic and social demographic analysis relied upon tabulated data and graphs to accommodate statistical and quantitative data. In contrast, the development of a master plan involved use of both coarse and measured and scaled graphic representations and physical, scaled-down models at an appropriate level of detail. The feasibility study required even more detailed and measured graphic representations to test spatial feasibility of individual building volumes. Tables and charts were also used to calculate and visualize economic feasibility in terms of investment and returns on the property over time.

Although there are variations to the organization of project team and development paths, most urban design and planning projects share a number of characteristics.

1. As illustrated in Figure 1, a number of representations are used by design participants to represent, analyze and propose solutions in urban design and planning projects. The characteristics of graphic representations are diverse, fragmented/ incomplete, subjective and often exclusive to a particular area of study.
2. Collaboration can comprise a number of stakeholders working in the same office

or distributed in multiple offices. The work is typically broken down into chunks of smaller sub-works, based on territoriality, sequence, special agenda, field of expertise, etc. The decisions therefore are distributed, delegated, coordinated, before eventually assembled into a shared final product. During the early phases, each stakeholder works mostly in isolation within his/ her own area of specialization, agenda, criteria, and representations.

3. Each design participant(s) choose(s) particular representations which best serve his/ her particular assigned purpose/ design task at hand. During these stages, participants typically work with incomplete and often fragmented information. As a result, global inferences cannot be undertaken synchronously with other related disciplines or are likely to be tentative. This consequently delays errors and mismatches to be detected earlier in the process. As the projects become more complex and encompass wider network of participants, the need for coordination increases and the necessity to fulfill constraints across a number of issues becomes important.
4. Another characteristic of such projects is the use of progressively detailed graphic representations. In the early planning stages, participants may rely on a high level of abstraction using diagrams, sketches, or simplified study model representations of choice. These representations are well suited in early phases of design projects when decisions are not fully committed to or may be only partial, and may be used to explore spontaneous and tentative negotiation. As the project development progresses, representations move from being abstract to more definite, they acquire more details, and may include scaled geometric representations and other data. In other words, representations evolve during development of projects. A specific representation may be appropriate only during a particular stage or context of use before it is replaced by another representation.

The preceding generalization of urban design and planning projects suggests that facilitating multiple representations and translations between them can lead to two advantages. First, it removes the exclusive partitions between different disciplines working together on a shared design project. It allows inferences to be made synchronously and dialectically with other design disciplines (indicated by horizontal direction between points 1-1 in Figure 2). Second, it supports inferences within each discipline using multiple representations (indicated by vertical direction between points 2-2 in Figure 2). To support such translation between multiple representations, we investigate a set of research issues in the following sections that are then implemented in a prototype computational environment.

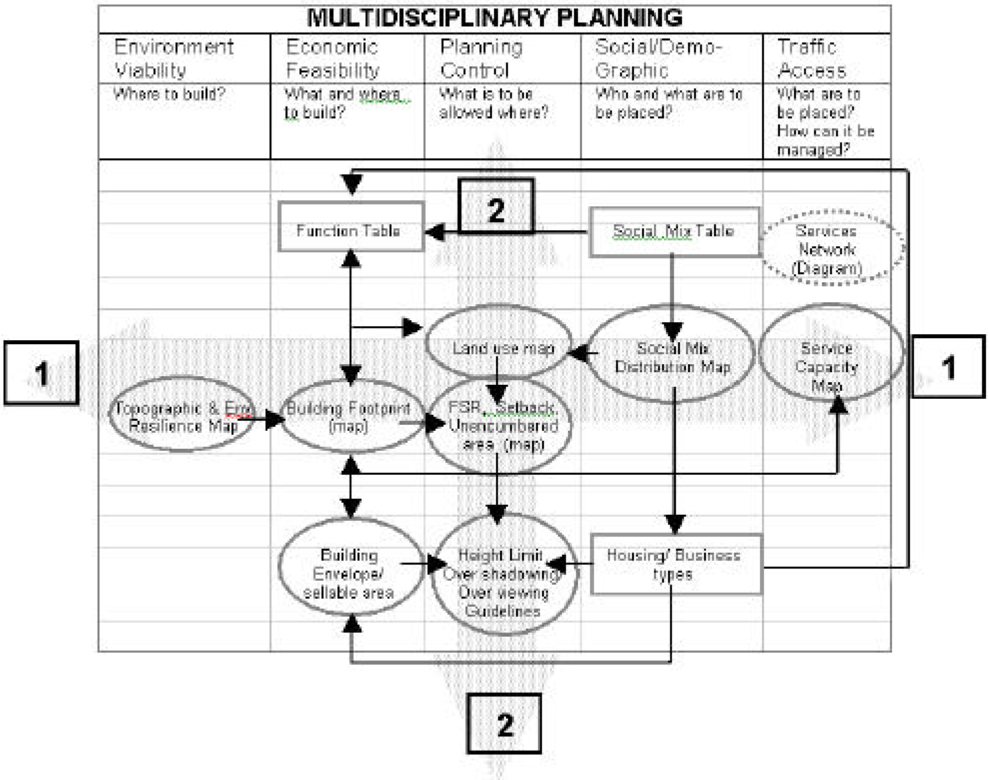

Figure 2: **Multiple agenda and representations underpin planning and design inference within and across the disciplines**

3 RESEARCH ISSUES

Ervin (Ervin, 1992) categorized graphic representations including diagrams, maps, graphs and pictures based on distinctive attributes of each representation as follows.

"Diagrams are **abstract and schematic** and are used to explore **structural relationships** between parts… Maps involve **scaled representations** using a consistent system of reference (e.g. coordinate system), and allow inferences about dimensional and **spatial relationships**… Graphs are concerned with representation of **statistical and quantitative** data…. Pictures are primarily concerned with **impression, expression and realism**." (Ervin, 1992)

Jones *et al.* (Jones et al., 1994) subsequently elaborated this taxonomy by emphasizing the benefits of translation between these representations. Recent computational advances augment the categorization through introduction of 2D and 3D spatial representations that allow either static or interactive manipulations.

To support the translation between these multiple representations, first it is necessary to understand attributes defining each respective group of representation. Pietsch (2000) has also reviewed issues of representational content and usability. She stresses that factors such as accuracy, abstraction and realism in graphic representations are vary in each representation and change dynamically throughout the design process. The following discussion identifies the significant attributes of representations.

3.1 **Data Format**

3.1.1 *Abstraction*

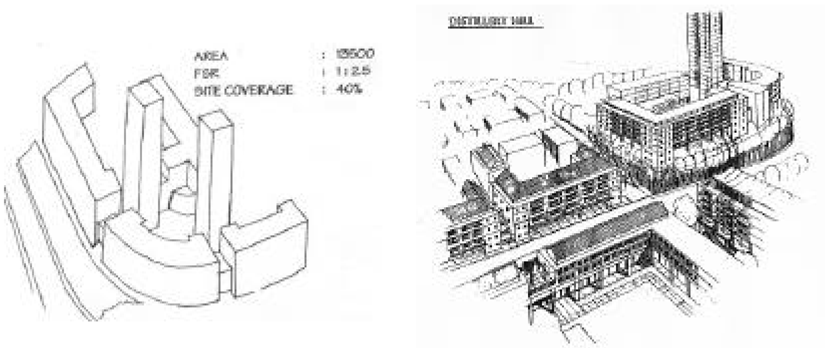

Figure 3: **Examples of representation with different levels of abstraction and realism** (from Pyrmont project).

The first significant dimension of graphic representation is encapsulation of an appropriate level of abstraction. Ervin used abstract and schematic variables in differentiating diagram from scaled or measured map. Level of abstraction reflects the level of detail or grain-size of information contained in a particular representation. Level of abstraction tends to decrease as the design progresses although this may not hold true in all circumstances. It also varies in accordance with the purposes of presentation. Higher level of abstraction requires representation of only key information whereas lower abstraction contains much more detailed information.

3.1.2 *Realism*

Another dimension of graphic representations, which is closely related to but different from the level of abstraction, is degree of realism. Realism is a measure of proximity of representation to associated real world situation. Photograph is an example where representation acquires a relatively high realism. According to Ervin (1992), realism together with expression and impression make pictures better suited at encoding visual renditions of phenomena.

3.2 **Data Content**

3.2.1 *Data domain*

The domain knowledge constrains what may or may not be represented as well as how it can be represented. From a computational perspective, managing translation between different domains of data content has to do with linking, documenting, coding, querying and retrieving of information across one or more discipline knowledge databases.

There are many potential problems in translations between representations. Sometimes, problems even arise while translating representations within one discipline domain; at other times, problems arise when translations require mapping of information from one discipline domain to another. As an example, translating any change from table to graph does not raise any problems but moving in the other direction may require additional domain knowledge. Similarly, one may extract a table of doors and windows schedule from a 3D model, however it would not be easy to traverse in reverse. At other times, translations may cross various data domains, for example, when an architectural layout requires a companion electrical or plumbing layout. Technically, the bottlenecks arise from many possible relations between representations, in particular:, many-to-many, and one-to-many translation.

3.2.2 *Data types*

The next research issue, which is closely bounded to the domain of knowledge is managing interpretation across different data types. It encompasses issues in translation between spatial and non-spatial representations, and quantitative and qualitative representations. A graphic representation such as map, for example, carries spatial information while others such as graphs, tabulated data or diagrams may not encode spatial information at the same level of detail. Between such different representations, two translations become almost impossible. When translation is from spatial to non-spatial representations, for example, spatial information may be lost in the process and it may be impossible to reverse that translation in an unambiguous way since there may be one-to-many possibilities.

Another example in translating different data types can be found in the translation between quantitative and qualitative representation. Ervin used the quantitative variable to specialize the use of graphs and tabulated data representation from other representations. In the context of translation between these different data types, the problems are similar to those involved in translation between spatial and non-spatial representations.

3.3 **Context of Use**

Planning is an iterative process comprising many generative and evaluative cycles. During the early stages of project development, the tentative nature of information can lead any changes and translations into generation of many planning and design alternatives. However as information becomes more definite and detailed with progressive development of the project, any changes and translations are most likely to be more constrained and localized. This is where manipulation of data attributes results in planning and design variants.

These two contexts involve different constraints and translation options. Translations from a tentative representation may require vast numbers of interpretation. This can be problematic if required interpretation knowledge cannot be supported through existing knowledge or rule based translation, dataset content or user's input. However translations at a more constrained environment are likely to require less interpretation variables. This is since more definitive constraints and interpretations have been acquired in the existing data content.

The preceding discussion highlights significant issues associated with translation of information across different representations that although sharing the same design context may originate from and be informed by entirely different knowledge bases of different collaborators. Our research is aimed at developing computational techniques that facilitate and support such translation between representations. A prototype was implemented to investigate these issues and is described next.

4 THE PROTOTYPE

The prototype application, called REX (Representation EXchange), demonstrates translations between four different representations: Map, Table, Graph, and 3DView. REX combines two separate prototypes developed previously, which are Map-Graph (Dave and Bishop, 2000), and Map-3DView. In REX, we start with map/table representation in the form of an ArcView shape file, and reflect these two representations into graph and 3D representations. Manipulation can be done either through the table, graph or 3D windows and changes will be reflected onto other representations. For instance, while working in the 3D representation, it is possible to drag a building envelope up and down to change its height. The change feeds back to the attribute table for the corresponding polygon. The change is reflected onto both the map representation (though changes in polygon color) and the land use distribution shown in the chart representation. The same result can also be achieved by manipulation of the commercial/ offices/ residential floor columns in the spreadsheet window. Navigation allows pan, zoom and rotate function to be performed in the 3D model window. This is done through execution of left, right or both mouse clicks. Zoom in, zoom out, pan, and window's reset button are provided for the 2D map window. At present development, we have implemented manipulation of building height's components (commercial, office, and residential) and related this manipulation into floor-space calculations. In future stages, we plan to include a wider area of applications such as economic feasibility, environmental impact assessment, or policy development.

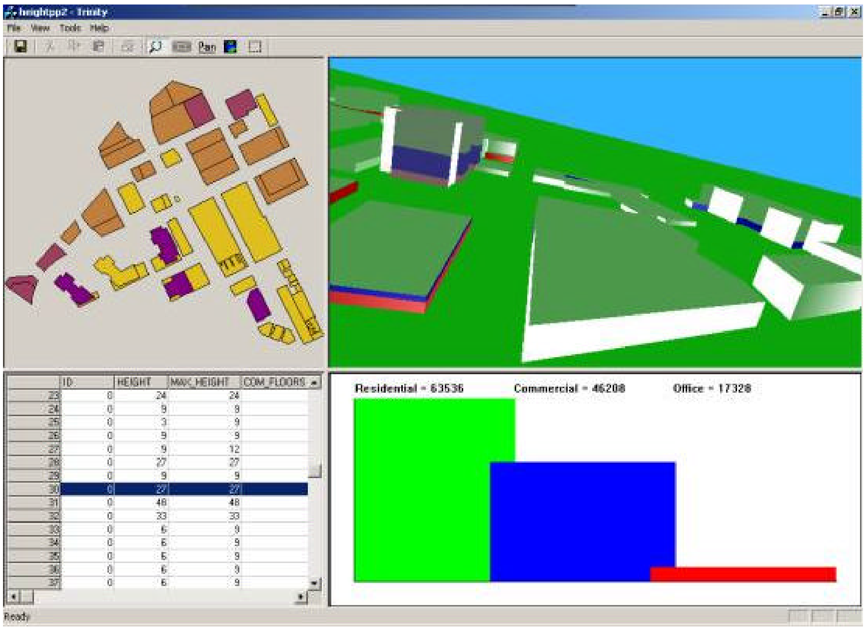

Figure 4: **REX User Interface consists of four windows representing Map, 3DView, Table and Graph Representations**

4.1 **Data Format**

The problem in translating between different levels of data content is that a one-to-one relationship cannot always be established in each translation. Therefore interpretation has to be made in order to resolve ambiguities. This is the typical situation in any translation towards lower levels of abstraction, higher realism or general to specific domain. Unless the context of use provides adequate information, there are two possible options in carrying out interpretation in such one-to-many relations. First, is to define knowledge-based rules of generation to automate the translation. Second, is to require user input to resolve ambiguities.

In REX, there are four representations and many possible translations. Because no editing is available in the map view and this is tightly linked to the map attributes though the attribute table, this can be treated in some respects as a single representation: the 'GIS view'. Here however we have treated them as separate entities because the potential exists to allow map editing though movement of vertices, this would then have clear consequences for all other representations. The approach to all possible translations is summarized in Table 1. To cope with one-to-many relations, for example, moving from the Map and Table to the 3Dview, we have incorporated knowledge-based interpretations to resolve ambiguity. In REX, for example, we took the general assumption that each additional floor is represented by a 3m height's increase in its 3Dview representation. This assumption could however be made explicit or varied through additional attribute columns. At present, in REX no manipulation can be initiated from Graph. Thus, for example, it is not possible to add commercial floors as the Graph is adjusted. However a capability as such, based on planning assumptions and user intervention can be implemented such as in our previous Map-Graph prototype. This can be seen in the Figure 5.

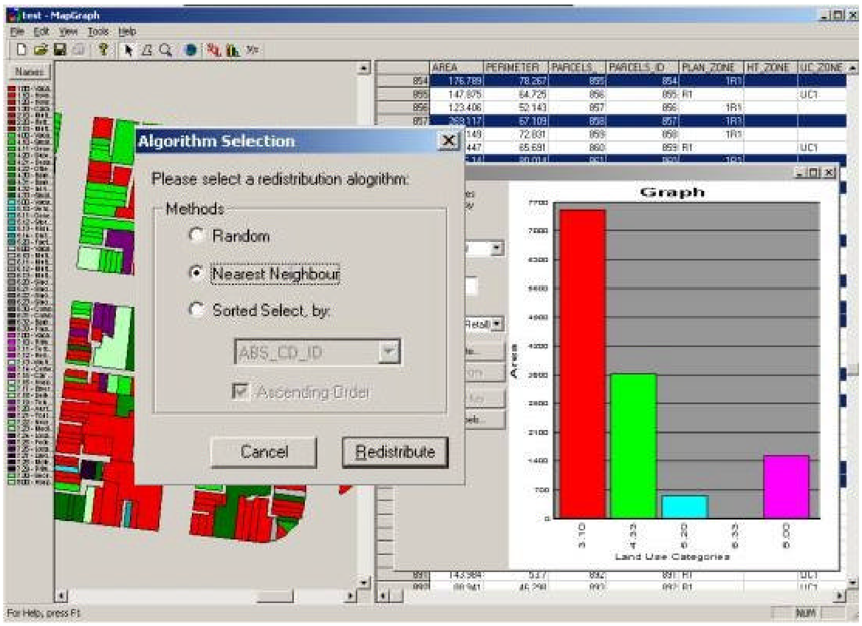

Figure 5: **Map-Graph allows many-to-one translation, through graph manipulation and additional user input.**

4.2 **Data Content**

In REX, data types can be differentiated as spatial or non-exclusive quantitative data (Map and 3DView) and non-spatial or quantitative data (Table and Graph). 3DView-Map and Table-Graph are two examples of translation within the same types of data. While 3Dview-Table-Graph or 3DView-Map-Table (and visa versa) are examples of translation between those two different data types. Table-Map, for example, passes the update of height table attribute so that it changes the color of the corresponding polygon.

The risk of data loss does not apply in REX as translations take place within the unified system. Thus, translation of data attributes in Map and 3D view representation to Table representation does not result in the loss of spatial data in 3D view representations. This allows re-generation of each representation based on inference between the existing dataset and the current manipulated attributes.

To: From:	MAP	TABLE	GRAPH	3D VIEW
MAP	-	Changes in map vertices will change values of area entity which will flow through to other views	Conventional abstraction of data as available in most GIS	Shape of extruded polygons changes accordingly
TABLE	**Changes in polygon colour reflecting some chosen attribute**	-	**Conventional abstraction of data as available in most GIS**	**3D drawing based on explicit (number of floors) and implicit (floor height) attributes**
GRAPH	*Occurs via Table*	*Ambiguity in allocation of land use changes. Resolved by user choice of random, lowest cost or proximity based reallocation*	-	Occurs via Table
3D VIEW	**Occurs via Table**	**Explicit if floor types edited individually. Ambiguous if whole building height changed. Allocation can be based on dominant use, pro rate distribution, lowest cost, highest return**	**Occurs via Table**	-

Table 1. **Approach to possible translation requirements in REX prototype.** (Plain text – not yet available, Bold text – available in REX, Italics– developed in earlier prototype) Extension to further representations – such as Diagram – can be accommodated.

4.3 **Context of Use**

We generate the initial dataset, map and spreadsheet, as an ArcView shape file. We manipulate the data in REX while receiving feedback in the four representations. Manipulation is REX's context of use, while generation is undertaken outside of the prototype, using ArcView (polygon and table), CAD (polygons only), and Excel (table only) applications. The benefit of working in the prototype with a highly constrained environment is that translations are facilitated within the existing dataset. There are less unambiguous interpretations as well as minimum risks of data loss resulting from translations between different data types or data contents. The deficiency of this environment is that it limits manipulation outside the predefined variables. Within REX, for example, we have to regenerate the map and attribute table in ArcView shape file to deal with changes in geometry of the plan or an additional column for new attributes. This is one of the impediments that exist at the current stage of development. REX is therefore a good environment to generate design variants rather than design alternatives

5 DISCUSSION

REX addresses problems in translation between representations by employing knowledge-based translation, within its unified system. This solution then is tied into a specific design task at a particular stage of design process. Some of the direct benefits of such a highly specialized application over a more general database/ drawing application include:

1. 3DView-Table and Table-3DView translations open a new two-ways communication channel between 'spatial interest' related disciplines and 'numeric interest' related disciplines. Previous general database applications (such as ArcView) provide communication in one direction only.
2. Similarly establishment of the Graph-Table-Map-3DView direction of translation would further extend system capabilities by allowing 3D Model manipulation to be accessed directly from Graph representation. This may reduce the time in the design production, when such a feature is necessarily helpful for that particular design task.
3. Although the current Table-Graph translation is restricted to reporting of land use data, it can be used for any other related design variable and applied to a wider area of interest/ discipline such as economic, social, environmental science, etc.
4. The accumulation of multiple representations and translations delivers an all-in-one work environment. Planning collaborators can work with their own preferred representation while also being exposed globally to its consequences in other related views. This should enhance understanding.

Consider the following application scenario. An architect proposes a development plan in his modeling application while a financial planner calculates the architect's plan in spreadsheet application. This involves sequential iteration of either the architect's plan or the financial planner's sheet before final decision is met. The sequential and fragmented nature of traditional decision making in design development results in repetitive cycles which could be optimized if both representations are linked with appropriate translation tools, such as REX.

If different representations highlights the different design variables relevant to different discipline's interest, then the long term benefit in using an application such as REX in a multi-disciplinary work environment can be indicated as:

1. Multiple representations extend individual discipline knowledge about other disciplines. This possibly opens the bottleneck in communication across the disciplines.
2. Two-way communication allows more active participatory decision-making in the

design process by providing access to manipulation from each representation.

The cross-discipline knowledge-based interpretation potentially disseminates wider understanding beyond any individual discipline. Therefore REX promotes collaborative design by embedding the multidisciplinary ingredients in the absence of such a multidisciplinary expertise. Although the knowledge-based interpretation facilitates highly automated translation, it leaves design manipulation and judgment to the human expertise. In a more flexible environment, such application should also allow user input into that so-called knowledge based interpretation.

6 CONCLUSION

Our experimentation with REX offers to the following two findings:
First, the prototype demonstrates that the 3Dview-Table translation has generated a possibility of two-way communication. This is a breakthrough in planning and design computation support, bearing in mind that GIS currently implements one-way translation only. Furthermore the two-way communication prospectively allows easy iterations in planning methods, which is previously constrained in the GIS application. This supports the recognition that planning is a trade-off mechanism between its many participants, agendas and criteria (Gross, et al. 1987). Hence multi-iterative editing becomes an essential feature that has to be addressed in any negotiation process.

Second, by using multiple representations, inference may be dynamically seen through various levels of abstraction and types of data. This allows participants to build their progressive 'seeing-doing-seeing' cycle, as Schon (Schon 1985) suggested in his reflection-in-action concept. For those disciplines that are previously limited in their representation options, this also opens a new way of seeing and working beyond their conventional practice. Some of the areas of the planning process that multiple representations can prospectively enhance are feasibility study, policy development, environmental impact assessment, community participation, as well as visualization it self.

Proposed further research and development includes:

1. As only limited design variables are currently incorporated, the potential benefits are similarly limited. In the next stage of development, more variables (potentially across the disciplines) will be included.
2. At this stage map representation in REX is not modifiable, as it is treated as part of the table representation as in GIS system. The next crucial development of the system is to treat the map as a modifiable representation. For example, manipulation can be executed to each of the polygon vertex, which has consequences in its other related data attributes in other window. This will add usability of the tools in the generation of design alternatives.

3. Representations are currently built to a relatively equivalent level of abstraction. This ties the applicability of REX into a very specific stage of the process and limits the scope of inference offered in this prototype. The inclusion of Diagram as a fifth alternative representation, and further level of abstraction, may be an advantage from a multi-level inference point of view.
4. The option of accommodating different thematic aspects in each representation has not been provided. This GIS like functionality can be enhanced by incorporating functions that enable the user to hide or unhide the selected object's attribute properties.
5. Application of building and ground textures in the 3Dview can enhance the realism of the view. Different textures can also be used to represent different land use types in more intuitive ways than simple color-coding.

Although it is outside this research aim, the 'ideal' would be for GIS and/or CAD software to extend their functionality to permit both generation and manipulation of design proposal through a range of representations to support both professional and educational purpose.

7 ACKNOWLEDGEMENT

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